Original Amplifier For Mode Division Multiplexing Based On Dual Core Erbium-Doped Fibre And Asymmetric Long-Period-Grating Converters

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An original concept of a Few-Mode Erbium Doped Fibre Amplifier (FMEDFA) based on a dual-concentric-core Erbium Doped Fibre (EDF) and paired mode converters is proposed for amplification of the LP_{11} and LP_{21} mode groups at 1530-nm wavelength with controlled Differential Modal Gain (DMG). As a proof of concept, we propose an EDF scheme that amplifies eight modes (including two polarizations and two orientations) of two mode-groups LP_{11} and LP_{21} input from a Few-Mode Fibre (FMF), with more than 20 dB of gain each. This concept is scalable to more mode groups and interesting for Mode Division Multiplexing (MDM).

The EDF has a dual concentric core structure: It consists of a central core (radius $r < a$) with index difference Δn_1, and a ring core ($b < r < c$) with relative index difference $\Delta n_2 > \Delta n_1$ with respect to pure silica cladding. A trench ($a < r < b$) with same index as silica separates the central and ring cores. The ring core is doped with Er^{3+} ions and works as the amplifying core. The schematic of the proposed amplifier is shown in Fig. 1(a). For the sake of clarity the LP mode-groups are often referred to as LP modes. The mode intensity profiles shown in Fig. 1(a) correspond to the fibre parameters chosen so that in the wavelength range of interest there is no resonance between the central core and the ring core for the desired sets of modes. There is sufficient mode spacing between the effective indices ($> 5\times10^{-4}$) of the modes to avoid mode coupling due to micro-bending [1]. Among the modes shown in Fig.1(a), $LP_{12,EDF}$ and $LP_{22,EDF}$ can be identified as core mode as their energy is mostly confined in the central core, whereas $LP_{21,EDF}$ and $LP_{31,EDF}$ have their energy mostly confined in the ring and can be identified as ring modes.

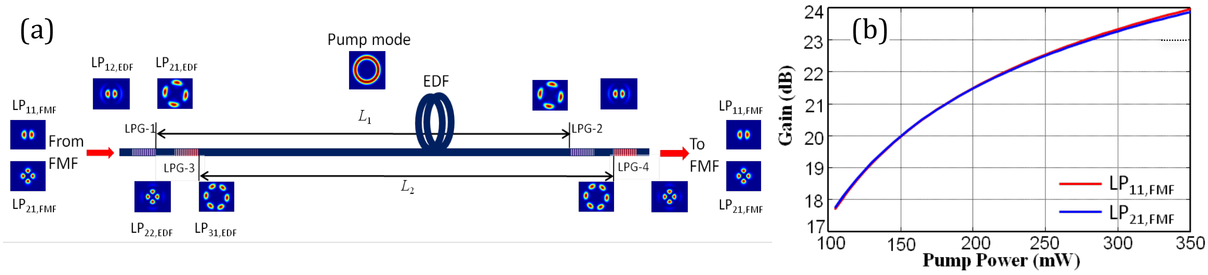

Fig. 1 (a) Schematic of the FMEDFA. FMF: few-mode input and output fibres, EDF: Er^{3+}-doped dual core fibre, LPG-i : asymmetric long pitch gratings (paired as 1-2 and 3-4), $L_{1,2}$: amplifying lengths for both mode-groups. (b) Variation of gain vs. pump power for L_1=17.8m ($LP_{11,FMF}$ mode group) and L_2=16.6m ($LP_{21,FMF}$ mode group). Gain (DMG) = 20 dB (0 dB) at 150 mW pump power. EDF parameters: $\Delta n_1 = 0.018$, $\Delta n_2 = 0.02$, $a = 4.5$ µm, $b = 6$ µm and $c = 9$ µm.

The input $LP_{11,FMF}$ and $LP_{21,FMF}$ modes of the line FMF excite the $LP_{12,EDF}$ and $LP_{22,EDF}$ core modes of the EDF. By using paired asymmetric long period grating (ALPG) converters, the $LP_{12,EDF}$ and $LP_{22,EDF}$ core modes excite the $LP_{21,EDF}$ and $LP_{31,EDF}$ ring modes, respectively. The asymmetric structure of the paired ALPG converters allows for the conversion of any mode symmetry to any other. We use a 4.3-cm long ALPG with a grating period of $\Lambda_1 = 479$ µm to couple light from $LP_{12,EDF}$ to $LP_{21,EDF}$ and a 9.6-cm long ALPG with a grating period of $\Lambda_2 = 198$ µm to couple $LP_{22,EDF}$ core modes to $LP_{31,EDF}$ ring modes for amplification. The ALPG refractive index modulation is 3×10^{-4}. After amplification, each ring mode is coupled back to its corresponding core modes via the corresponding paired ALPG. We choose the $LP_{02,EDF,p}$ pump mode of EDF for amplification. The EDF parameters are chosen to equal the overlap of the $LP_{02,EDF,p}$ with each $LP_{21,EDF}$ and $LP_{31,EDF}$ modes. The gain for each mode group is independently decided by the distances $L_{1,2}$ between the in- and out-coupling paired ALPGs. A suitable choice of L_1 and L_2 is used to achieve any desired DMG value.

Numerical simulations show that for 150 mW pump power injected in the $LP_{02,EDF,p}$ mode and 30 µW in each signal channel, more than 20 dB is achieved for both modes groups, and that DMG is less than 0.69 dB if $L_1 = L_2 = 17.8$ m. For example, this residual DMG can be minimized by optimizing L_1 and L_2 : DMG = 0 dB (150 mW) with $L_1 = 17.8$ m and $L_2 = 16.6$ m (Fig1(b)). Alternatively, by equally exciting all the supported pump modes of the EDF (instead of only $LP_{02,EDF,p}$) with a total of 168 mW power leads to gain > 20 dB and DMG < 0.71 dB only for equal amplifier length > 20.7 m. Here also, $L_{1,2}$ optimization allows for DMG control.

References

[1] S. Ramachandran, J. W. Nicholson, S. Ghalmi, M. F. Yan, P. Wisk, E. Monberg, and F. V. Dimarcello, “Light propagation with ultralarge modal areas in optical fibers,” Opt. Lett. **31**(12), 1797-1799 (2006).

[2] R. Slavik, “Coupling to circularly asymmetric modes via long-period gratings made in standard straight fiber,” Opt. Comm. **275**(1), 90-93(2007).